Downhole Oil & Water Separation
A New Start

Presenter: Ed Sheridan
Baker Hughes
SubSep - Downhole Oil & Water Separation

- Summary of Previous Experience
- What has changed?
- New Design
- China Application
- China Design
- China Performance
- System operation
- Technical Requirements
- Keys to Success
Previous Completion Design

Key Issues:

• Non-standard ESP design with 2 pumps on 1 motor

• Not able to use ESP monitoring systems due to motor position

• No method for verifying what was being injected

• By-pass tubing used for feed to upper pump
What has changed?

The table highlights the key differences between the previous systems & the new design & how it mitigates some of the risks:

<table>
<thead>
<tr>
<th>Previous SubSep Installations</th>
<th>Risk</th>
<th>New SubSep Completion Design</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single system comprising one motor driving 2 pumps</td>
<td>![Old Risk]</td>
<td>Two separate systems, sized for range of expected duties</td>
<td>![New Risk]</td>
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<tr>
<td>Both pumps running at same frequency</td>
<td>![Old Risk]</td>
<td>Each system, independently controllable</td>
<td>![New Risk]</td>
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<tr>
<td>No means of monitoring exactly what is being injected</td>
<td>![Old Risk]</td>
<td>Sample line to surface to allow testing of injection water</td>
<td>![New Risk]</td>
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<tr>
<td>Monitoring only on ESP system for protection &amp; optimization</td>
<td>![Old Risk]</td>
<td>Monitoring on ESPs &amp; additional monitoring on intake &amp; discharge of the subsep</td>
<td>![New Risk]</td>
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<tr>
<td>Subsep design involved by-pass tubing on outside of the hydrocyclone to direct flows as required</td>
<td>![Old Risk]</td>
<td>Subsep will be supplied as a &quot;ready-made&quot; sub-assembly with all internal plumbing pre-installed &amp; protected inside the housing with &quot;plug &amp; play&quot; design for install crew</td>
<td>![New Risk]</td>
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<tr>
<td>Special design due to two pumps running off of one motor utilizing non-standard additional components</td>
<td>![Old Risk]</td>
<td>Utilizes standard equipment as already in operation for dual wells with only addition of the SubSep hydrocyclone &amp; associated monitoring</td>
<td>![New Risk]</td>
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<tr>
<td>Utilized standard well head &amp; tubing hanger</td>
<td>![Old Risk]</td>
<td>Requires additional TEC wire penetration through the tubing hanger to allow SubSep monitoring</td>
<td>![New Risk]</td>
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New Design - Philosophy

- To address the concerns raised & lessons learned from previous installations
- To simplify the SubSep system & completion design
- To keep the ESP part of the completion the same whether the Injection Zone is above or below the Production Zone
- Keeping ESP section the same would allow a standardized control & operation methodology to be developed.
- Wherever possible, use only standard equipment already commonly in use for ESP completions
- Update the SubSep hydrocyclone to a “plug & play” design
- Use a Sample Line to verify separation efficiency
New Design - System Schematic

FROM RESERVOIR

DOWNHOLE

- Lower ESP
- SubSep (Separated Water)
- Upper ESP

SURFACE

- Chemical Injection
- Control & Monitoring
- VSD (Lower)
- VSD (Upper)

FLOW PATHS

- Oil Rich Stream
- Surface Choke
- To Production
- To Test Separation efficiency
- Sample Line
System Operation

- Fluid from Production Zone flows into the lower ESP and then on to the SubSep at required pressure.
- Separated Water stream directed to the injection zone above the Production Zone.
- Separated oil rich fluid is forced to the Upper ESP which is used to produce to the surface.
- Injection stream water can be sampled at surface or flow direction can be reversed for chemical injection.
System Operation

- System uses 2 independently controlled ESPs on 2 Variable Speed Drives
- Allows control over a wide range of PI & II conditions
- Allows control of water split between Injection Zone & Surface to maximize separation efficiency
- Sample line can also be used for chemical injection into the disposal zone
- Full monitoring capability included
How does SubSep work?

Performance Example:
10,000 bfpd well with 90% water cut & separating 8,000 bwpd to injection zone

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<td><strong>Injected Fluid</strong></td>
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<td>8000</td>
<td>&lt; 500 ppm</td>
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<tr>
<td><strong>Well Fluid</strong></td>
<td>10000</td>
<td>9000</td>
<td>1000</td>
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Technical Requirements

Need to have:

• Casing ≥ 7” 26#
• Water cut ≥ 85%
• Good well data available for injection & production zones – vital for success
• Density differential ≥ 10% of Oil Sp. Gr.
• Clean Well – minimal to no solids

Recommended:

• Injectivity Testing
• Include the Sample Line
• 2 x Variable Speed Drive
• Adjustable surface choke
• Use of Downhole Monitoring systems
• BFPD ≥ 3,000 BPD
Well Selection is Critical

- Candidate Selection Issues: 43%
- Conventional Failures: 29%
- Other: 3%
- SubSep Failures: 25%
China Case Study

• Background – Operator in Bohai Bay, China
  – Faced with surface water constraints & pressure to reduce overboard dumping
  – Already using dual-can ESPs systems
  – Already injecting into the disposal zone via injector wells so good data / history available

• Solution – SubSep Downhole Separator with Dual ESPs
  – Added the SubSep & associated gauge into their standard completion
  – Installed Excluder screens at the Injection Zone
  – Injected chemicals at the inlet to the SubSep
China Bohai Bay Well Selection

• Water cut > 90%
• Oil rate > 300 bopd with the potential to maintain good flow rates for several years
• Downhole viscosity <10 cp and gravity as high as possible,
• ESP that had failed or was close to its target run life i.e. +/-2.5 years or longer
• Wellbore penetrates a good disposal or injection target and that can take up 10,000 bfpd with minimal injection pressure,
• Disposal or injection zone that is located below or near our pump setting depth but above the sand control packer.
• Well Completed in 9 5/8” 47# production casing
• A well which hadn’t produced excessive gas or solids
• Accessible with the platform based Workover rig
### Selection Criteria

1. Water cut > 90%
2. Oil rate > 300 BOPD
3. API > 15 degs, Viscosity < 30cp
4. ESP run-life +/-2.5 years as of today.
5. Good disposal target with high Injectivity
6. No excessive gas or solids

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<th>Production Zone</th>
<th>Well</th>
<th>Reservoir</th>
<th>WCT</th>
<th>Pi</th>
<th>Remaining Reserves (MMBO)</th>
<th>Oil API(Surface)</th>
<th>Viscosity(cp)</th>
<th>Pump Runtime (days)</th>
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CFD 11-2A-17H

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**SUBSEP INLET**

- Oil = 210 B/D
- Water = 10290 B/D
- Total = 10500 B/D
- W-Cut = 98.0%
- Pressure = 1761 psi

**SUBSEP OVERFLOW**

- Oil = 210 B/D
- Water = 1490 B/D
- Total = 1700 B/D
- W-Cut = 87.6%
- Overflow Split = 16.2%
- Pressure = 1317 psi

**PRESSURE DROP BETWEEN OVERFLOW OUTLETS**

- Vertical Separation = 10 feet
- Tubing OD = 0.75 inches
- # of Tubes = 1
- Oil API = 23.8
- Water Sp. Gr. = 1.01
- Total Viscosity = 0.5 cp
- Pressure Drop = 183 psi

**SUBSEP #2**

- PDR = 2.42
- Orifice = 4.91 mm
- # of Cyclones = 5
- Pr.-drop = 444 psi

**SUBSEP #2 UNDERFLOW**

- Depth = 3298 feet
- Oil = 0 B/D
- Water = 8800 B/D
- Total = 8800 B/D
- W-Cut = 100%
- Vol. Split = 83.8%
- Pressure = 1577 psi

**Injection Tubing**

- Tubing ID = 8.869 inches
- Press. Drop = 419 psi

**INJECTION ZONE**

- Depth = 4256 feet
- Static Pr. = 1836 psi
- Inj. Index = 55.0 B/D/psi
- Injection Press. = 1996 psi
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<td>224 83 2.7</td>
<td>2.7 10</td>
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<td>7000</td>
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</table>
Performance Update

Before workover:
• Total Fluid to surface: 7000bfpd @ 97.7%WC (6839 bwpd / 161 bopd)

Current status: Lower ESP Upper ESP
• Intake Pressure: 1371 psi No Data (1467* psi)
• Discharge Pressure: 2263 psi No Data (1637* psi)
• Freq: 60 Hz 56 Hz
• Rate: 11425 bfpd 2331 bfpd (2051 bwpd / 280 bopd)
• WC: 97.5% 88%

Injection Zone
• Pressure at start up: 1611 psi
• Pressure current: 2092 psi
• Oil Carry Over: 125 ppm
• Water injected: 9,094 bwpd

* Last data prior to 1 phase to grnd
Performance Update

SubSep Installed

Total Fluid to Surface (M3/d)
Total Water to Surface (M3/d)
Total Oil to Surface (M3/d)
Performance Update

SubSep Installed
CONTROL LOGIC

Operating Scenarios

• Changes in Stable Operations
  – Change in I.I.
  – Change in P.I.
  – Change in target production rate
  – Change in static reservoir pressure
  – Change in sample line p.p.m. (or loss of sample line)
  – Change in oil rich w/c

• Loss of Monitoring System
  – Loss of Lower ESP gauge
  – Loss of Upper ESP gauge
  – Loss of Injection Zone gauge

• Loss of ESP
  – Loss of Lower ESP requires completion to be pulled
  – Loss of Upper ESP modified Ops with reduced control possible.
Keys to Success

• Careful Selection of Candidate Well
• Partnership with operator
• Disposal Zone Understanding
  – Injectivity Index needs to be clearly understood with good data
• Separation System
  – Separator successfully installed and operating (Oil < 500 ppm)
  – Two stage separator available for further reduction in oil ppm.
  – Sample line to verify separation efficiency & allow optimization
• Completion Design
  – Good ESP design data for Application Engineering
  – Use of standard completion equipment & techniques
  – Use of Downhole Monitoring of all key parameters
  – Use of sand control to limit solids production
Don’t Just Count What is Produced: Produce What Counts!